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First Evidence for a Charm Radial Excitation, $D^{*\prime}$

DELPHI Collaboration

Abstract

Using D^{*+} mesons exclusively reconstructed in the DELPHI detector at LEP, an excess of 66 ± 14(stat.) events is observed in the $D^{*+}\pi^+\pi^-$ final state with a mass of 2637 ± 2(stat.) ± 6(syst.) MeV/c^2 and a full width smaller than 15 MeV/c^2 (95% C.L.). This signal is compatible with the expected decay of a radially excited $D^{*\prime}$ ($J^P = 1^-$) meson.

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1 Introduction

In the spectroscopy of charm mesons, the D and D^* ground states are well established while only the narrow orbital excitations D_1 and D_2^* have been clearly observed so far [1]. For mesons containing heavy and light quarks ($Q\bar{q}$) and in the limit where the heavy quark mass is much larger than the typical QCD scale ($m_Q \gg \Lambda_{QCD}$), the spin $\vec{s}_Q$ of the heavy quark and the total (spin+orbital) angular momentum $\vec{j}_q = \vec{s}_q + \vec{L}$ of the light component are separately conserved by the strong interaction [2]. This heavy quark symmetry, together with quark potential models used for lower mass mesons, allows the masses and decay widths of heavy mesons of total spin $\vec{J} = \vec{s}_Q + \vec{j}_q$ to be predicted [3–7]. The D and D^* correspond to the two degenerate levels of the ($L = 0$, $j_q = 1/2$) state. The $L = 1$ orbital excitations are grouped into two degenerate levels with $j_q = 1/2$ and $j_q = 3/2$. The $j_q = 1/2$ states decay through an S-wave and are expected to have a large decay width, whereas the $j_q = 3/2$ states decay through a D-wave and are narrow. This scheme is summarized in table 1 for non-strange charmed mesons. The $D_1(2420)$ and $D_2^*(2460)$ have been observed with decay widths of about 20 MeV/c^2 and are identified as the states with $j_q = 3/2$ and $J^P = 1^+$ and 2^+, respectively [1]. Orbitally excited beauty mesons are expected to present a similar scheme.

	J^P j_q		Mass (MeV/c^2)	, Width (MeV/c^2)	Decay modes
D_0^*	0^+ 1/2		~ 2360	≥ 170	($D\pi$)
D_1'	1^+ 1/2		~ 2430	≥ 250	($D^*\pi$)
D_1	1^+ 3/2	D_1^+	2427 ± 5	28 ± 8	$D^{*0}\pi^+$ ($D^{*+}\pi^0$, $D\rho$, $D\pi\pi$)
		D_1^0	2422.2 ± 1.8	$18.9^{+4.6}_{-3.5}$	$D^{*+}\pi^-$ ($D^{*0}\pi^0$, $D\rho$, $D\pi\pi$)
D_2^*	2^+ 3/2	D_2^{*+}	2459 ± 4	25^{+8}_{-7}	$D^0\pi^+$, $D^{*0}\pi^+$ ($D^{(*)+}\pi^0$, $D^*\rho$, $D^*\pi\pi$)
		D_2^{*0}	2458.9 ± 2.0	23 ± 5	$D^+\pi^-$, $D^{*+}\pi^-$ ($D^{(*)0}\pi^0$, $D^*\rho$, $D^*\pi\pi$)

Table 1: Expected and observed $L = 1$ orbital excitations of D^0 and D^+ mesons. The broad $j_q = 1/2$ states are estimated according to [7]. The narrow $j_q = 3/2$ states are measured [1]. In the last column, those predicted decay modes which are not yet observed are indicated within parentheses.

In addition to these orbital excitations, radial excitations of heavy mesons are also foreseen. Based on a QCD inspired relativistic quark model, the D' ($J^P = 0^-$) and $D^{*\prime}$ ($J^P = 1^-$) are expected with masses of 2.58 GeV/c^2 and 2.64 GeV/c^2, respectively, with a 10-25 MeV/c^2 uncertainty on the mass predictions [4]. A recent relativistic quark model, which requires no expansion in function of the lightest quark mass, predicts masses of 2.58 GeV/c^2 and 2.63 GeV/c^2, respectively, with an agreement of better than 20 MeV/c^2 for the observed charm orbital states [8]. The dominant decay modes of the D' and $D^{*\prime}$ are expected to be into $D\pi\pi$ and $D^*\pi\pi$, respectively, but decays into $D^{(*)}\rho$ or through an intermediate orbital excitation are not excluded. Decays with a single pion in the final state would require a P-wave transition and should be suppressed. However no firm estimate of the decay widths is available. The decay amplitudes of known light quark mesons are reasonably well described using harmonic oscillator wave functions for the initial and final state mesons [6]. Using this approach for charm mesons provides an

estimate of the $D^{*\prime}$ partial decay widths of less than one MeV/c^2 in the $D^*\pi\pi$ final state and less than a few MeV/c^2 in the $D_1^{(\prime)}\pi$ final state. Figure 1 shows the spectrum of the various D mesons with their decay modes involving S-, P- or D-wave transitions. In the B sector, a narrow resonance compatible with the expectation of a $B^{(*)\prime}$ decaying into $B^{(*)}\pi^+\pi^-$ has been reported [9].

This letter presents evidence for a narrow $D^{*+}\pi^+\pi^-$ resonance [1] using about 3 million Z decays observed in DELPHI from 1992 to 1995. The D^{*+} candidates are selected in the exclusive decay channels $D^{*+} \to D^0\pi_*^+$ followed by $D^0 \to K^-\pi^+$ or $D^0 \to K^-\pi^+\pi^+\pi^-$. Then the known D_1^0 and D_2^{*0} decaying into $D^{*+}\pi^-$ are used in order to check the vertex finding procedure and the invariant mass estimate. Finally, $D^{*+}\pi^+\pi^-$ final states are considered.

2 The DELPHI detector

The DELPHI detector and its performance have been described in detail elsewhere [10,11]; only those components relevant for the present analysis are discussed here.

The tracking of charged particles is accomplished in the barrel region with a set of cylindrical tracking detectors whose axes are oriented along the 1.23 T magnetic field and the direction of the beam.

The Time Projection Chamber (TPC), the main tracking device, is a cylinder of 30 cm inner radius, 122 cm outer radius and length 2.7 m. For polar angles between 39° and 141° it provides up to 16 space points along the charged particle trajectory.

The Vertex Detector (VD), located nearest to the LEP interaction region, has an intrinsic Rϕ resolution of 5–6 μm, transverse to the beam direction, and consists of three concentric layers of silicon microstrip detectors at average radii of 6.3 cm, 9.0 cm, and 10.9 cm. The layers surround the beam pipe, a beryllium cylinder of inner radius 5.3 cm and wall thickness 1.45 mm. In the earlier runs all the VD layers were single-sided with strips parallel to the beam axis. In 1994 and 1995 the innermost and the outermost layers were replaced by double-sided silicon microstrip modules, allowing measurements to be made parallel to the beam.

The VD, the Inner Detector (ID), the TPC and the Outer Detector (OD), measure the charged particle tracks at polar angles, θ, between 30° and 150°. Combining the information from these detectors, a resolution, $\sigma(p)/p$, of $\pm 3.0\%$ has been obtained for muons of 45 GeV/c momentum.

Hadrons are identified using the specific ionization (dE/dx) in the TPC and the Cherenkov radiation in the barrel Ring Imaging CHerenkov detector (RICH) placed between the TPC and the OD detectors.

The tracking in the forward ($11° < \theta < 33°$) and backward ($147° < \theta < 169°$) regions is improved by two pairs of Forward drift Chambers (FCA and FCB) in the end-caps.

3 The event sample and the simulation

Charged particles were selected as follows: the momentum had to be between 0.1 GeV/c and 50 GeV/c, the relative error on momentum measurement less than 100%, the track length in the TPC had to be larger than 30 cm, the projection of their impact parameter relative to the interaction point had to be below 4 cm in the plane transverse

[1] Throughout the paper charge-conjugate states are implicitly included and the pion from the D^{*+} decay is denoted π_*^+.

to the beam direction and the distance to the interaction point along the beam direction below 10 cm.

Hadronic events were selected by requiring five or more charged particles (of momentum larger than 0.4 GeV/c) and a total energy of charged particles larger than 12% of the collision energy, assuming all charged particles to be pions. A total of 3.4 million hadronic events was obtained from the 1992-1995 data at centre-of-mass energies close to the Z mass.

Simulated hadronic events were generated with the JETSET 7.3 Parton Shower program [12]. The generated events were followed through a detailed detector simulation [11] which included simulation of secondary interactions and digitization of all electronic signals. The simulated data were then processed through the same analysis chain as the real data.

In order to estimate the reconstruction efficiencies and the invariant mass resolutions, some dedicated samples of events containing a D_1^0 or D_2^{*0} decaying into $\mathrm{D}^{*+}\pi^-$, or a $\mathrm{D}^{*'}$ decaying into $\mathrm{D}^{*+}\pi^+\pi^-$, were generated. Both modes $\mathrm{D}^{*+} \to \mathrm{D}^0\pi_*^+$ with $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ or $\mathrm{D}^0 \to \mathrm{K}^-\pi^+\pi^+\pi^-$ were simulated. The $\mathrm{D}^{*'}$ mass was arbitrarily fixed to 2640 MeV/c^2.

4 D^{*+} meson reconstruction

The primary interaction vertex was computed in space for each event using an iterative procedure based on the χ^2 of the fit of all charged particle trajectories [11]. The average transverse position of the interaction point, measured for each fill, was included as a constraint during the primary vertex fit.

For the D^0 from D^{*+} decay, all $\mathrm{K}^-\pi^+$ and $\mathrm{K}^-\pi^+\pi^+\pi^-$ combinations were tried to fit a secondary vertex in space. The D^0 momentum was taken as the sum of the momenta of the decay products from this secondary vertex. Kaon candidates were considered if they had a momentum larger than 1 GeV/c. Pion candidates were considered if they had a momentum larger than 1 GeV/c in the Kπ channel and 0.5 GeV/c in the K3π channel. At least two particle tracks from the D^0 decay were required to have at least one hit in the VD. A distance ΔL was computed between the primary and secondary vertices in the plane transverse to the beam axis. This distance was given the same sign as the scalar product of the D^0 momentum with the vector joining the primary to the secondary vertices.

The D^0 apparent proper time $t(\mathrm{D}^0)$ was defined as $t(\mathrm{D}^0) = \Delta L \cdot M(\mathrm{D}^0)/p_t(\mathrm{D}^0)$ where $M(\mathrm{D}^0)$ is the reconstructed mass of the D^0 and $p_t(\mathrm{D}^0)$ is its transverse momentum relative to the beam axis.

To reduce the combinatorial background in the Kπ channel where no K identification was applied, the angle θ^* between the D^0 flight direction and the kaon direction in the D^0 rest frame was required to satisfy the condition $\cos\theta^* > -0.9$. For genuine D^0 candidates an isotropic distribution in $\cos\theta^*$ is expected whereas the background is strongly peaked in the backward direction.

In the K3π channel further selections were required to reduce the combinatorial background: an impact parameter, computed in the plane transverse to the beam direction, of each charged particle track relative to their common D^0 vertex smaller than 300 μm, a χ^2 probability of the D^0 vertex larger than 1%, a kaon candidate compatible with the expectation according to the combined RICH and dE/dx identification and a positive distance ΔL.

Then all charged particles with momentum between 0.4 GeV/c and 4.5 GeV/c and charge opposite to that of the kaon candidate of the D^0 were used as pion candidates

for the $D^{*+} \to D^0\pi_*^+$ decay. The D^{*+} candidates were selected if their energy fraction $X_E(D^{*+}) = E(D^{*+})/E_{\rm beam}$ was larger than 0.25.

In the Kπ (K3π) channel, events were selected if the mass difference $M(K\pi\pi_*)-M(K\pi)$ ($M(K3\pi\pi_*) - M(K3\pi)$) was within ± 2 (± 1) MeV/c^2 of the nominal ($D^{*+}-D^0$) mass difference.

The invariant mass distributions $M(K^-\pi^+)$ and $M(K^-\pi^+\pi^+\pi^-)$ are shown in figure 2. They were each fitted by using the following contributions: the exponential of a second order polynomial function for the combinatorial background and the sum of two Gaussian functions (of common mean) for the D^0 candidates. A parameterization of the $D^0 \to K^-\pi^+\pi^0$ reflection (with free normalization) was also included in the fit of the $K^-\pi^+$ invariant mass distribution. The fitted D^0 mass is 1868 ± 1 (1869 ± 1) MeV/c^2 and the observed r.m.s. width of the narrower Gaussian is 19 ± 1 (12 ± 1) MeV/c^2 in the Kπ (K3π) channel. In both decay modes, the measured D^0 mass was found about 4 MeV/c^2 above the expectation of 1864.5 ± 0.5 MeV/c^2 [1]. This deviation has a negligible contribution to the systematic error described later.

In the following, for the Kπ (or K3π) channel, the mass difference will be required to lie within ± 2 (± 1) MeV/c^2 of the nominal ($D^{*+}-D^0$) mass difference and the reconstructed D^0 invariant mass to lie within ± 40 (± 30) MeV/c^2 of the nominal D^0 mass. These selections provided 4661 ± 88(stat.) and 2164 ± 65(stat.) reconstructed D^{*+} in the respective channels.

5 Search for orbitally excited D mesons

In this section a search for orbitally excited D_1^0 and D_2^{*0} mesons decaying into $D^{*+}\pi^-$ is presented. Using the pion from the $D^{*+} \to D^0\pi_*^+$ decay, a $D^0\pi_*^+\pi^-$ vertex can be fitted. In the next section a similar vertex fit is applied to the search for $D^{*+}\pi^+\pi^-$ final states. The study of the well known D_1^0 and D_2^{*0} mesons can thus be used as a test of the method.

In the $D^{*+}\pi^-$ final state, all pion candidates of charge opposite to the D^{*+} and momentum greater than 1.0 (1.5) GeV/c were considered in the Kπ (K3π) channel. Then, the pion from $D^{*+} \to D^0\pi_*^+$ decay was used to fit a $D^0\pi_*^+\pi^-$ vertex. At least one pion had to be detected in the VD. In the $D^0 \to K^-\pi^+$ channel, the additional π^- was selected if its impact parameter with respect to the common $D^0\pi_*^+\pi^-$ vertex was less than 50 μm. This requirement was not used in the K3π channel due to the better definition of D^0 decay vertex in this case.

To estimate the $M(D^{*+}\pi^-)$ invariant mass, the mass difference $M(D^{*+}\pi^-) = M(D^0\pi_*^+\pi^-) - M(D^0\pi_*^+) + m_{D^*}$ was computed, where m_{D^*} is the nominal D^{*+} mass [1]. According to the simulation, this gives a resolution of about 6 MeV/c^2 on $M(D^{*+}\pi^-)$ with no bias in the mass computation.

This invariant mass distribution is presented in figure 3 for the selected events. An excess of $(D^{*+}\pi^-)$ pairs is observed between 2.4 and 2.5 GeV/c^2, but not in the $(D^{*+}\pi^+)$ sample. The $M(D^{*+}\pi^-)$ distribution was fitted as the sum of three contributions: a function of the form $\alpha(M(D^*\pi) - m_{D^*} - m_\pi)^\beta \cdot \exp(-\gamma(M(D^*\pi) - m_{D^*} - m_\pi))$ for the background, where m_π is the pion mass, and two functions describing both D_1^0 and D_2^{*0} resonances. Each resonance shape was parameterized as the convolution of a Breit-Wigner and a Gaussian function of same mean value. The full width of each Breit-Wigner function was fixed to its world average value [1] (see table 1) and the width of the Gaussian shape was set to the estimated mass resolution of 6 MeV/c^2. The overall number and relative proportions of the resonant states and their average masses were left free in the fit. A total number of 361 ± 58 D_1^0 and D_2^{*0} was observed of which $(65\pm10)\%$ was assigned to the

D_1^0 meson. The fitted masses were 2425 ± 3 MeV/c^2 for the D_1^0 and 2461 ± 6 MeV/c^2 for the D_2^{*0} resonances, in agreement with their world average values of 2422 ± 2 MeV/c^2 and 2459 ± 2 MeV/c^2, respectively [1]. All fitted errors are statistical only.

6 Search for a radially excited D meson

Repeating a similar procedure as above, all remaining opposite charge $\pi^+\pi^-$ pairs produced in the same direction as the D^{*+} candidates were used to fit a $D^0\pi^+\pi^-$ vertex. In the Kπ (K3π) channel, the additional pions were required to have a momentum larger than 0.6 (1.0) GeV/c. Those pion candidates compatible with a kaon according to the combined RICH and dE/dx identification were rejected. The energy fraction $X'_E(D^{*+}\pi^+\pi^-)$ and the decay length $\Delta L'$ (with an uncertainty $\sigma_{L'}$) of the $D^0\pi^+\pi^-$ vertex were computed. In order to reduce further the combinatorial background, only events belonging to $b\overline{b}$ or $c\overline{c}$ enriched samples were retained. In the $b\overline{b}$ sample the probability, P_E [11,13], that all charged particles originate from the primary vertex was required to be smaller than 0.01 and the decay length significance $\Delta L'/\sigma_{L'}$ had to be larger than 2. If these selections were not fulfilled, the D^0 apparent proper time, defined in section 4, was required to be larger than 1 ps. In the $c\overline{c}$ sample, a significance $|\Delta L'/\sigma_{L'}|$ less than 2, a D^0 apparent proper time less than 1 ps, and either a P_E value larger than 0.1 or an energy fraction X'_E greater than 0.4 were required. According to the simulation, the fraction of genuine $b\overline{b}$ ($c\overline{c}$) events was $84 \pm 2\%$ ($87 \pm 2\%$) in the enriched samples.

The reconstructed invariant mass was computed with a procedure similar to that described in section 5: $M(D^{*+}\pi^+\pi^-) = M(D^0\pi_*^+\pi^+\pi^-) - M(D^0\pi_*^+) + m_{D^*}$. This gives a resolution of about 6 MeV/c^2 and no bias, according to the simulation. The invariant mass distribution of all $D^{*+}\pi^+\pi^-$ candidates is presented in figure 4. A narrow peak is observed whereas the wrong charge combinations $D^{*+}\pi^-\pi^-$ do not show any excess. A binned maximum likelihood fit to the mass distribution was performed by taking into account two contributions: a function of the form $\alpha(M(D^*\pi\pi) - m_{D^*} - \mu)^\beta \cdot \exp(-\gamma(M(D^*\pi\pi) - m_{D^*} - \mu))$ for the background, with μ set to 340 MeV/c^2, and a Gaussian function with free parameters to describe the narrow peak. The χ^2 per degree of freedom was 60/59 (it would be 91/62 if the fit was performed with the background shape only, without the Gaussian function). The fitted number of events was 66 ± 14 with a significance of 4.7 standard deviations. The fitted width was 7 ± 2 MeV/c^2, in agreement with the expected resolution, and the average mass was found to be 2637 ± 2 MeV/c^2. About $(57 \pm 10)\%$ of these events were selected in the $c\overline{c}$ enriched sample. Only statistical errors are quoted.

A Breit-Wigner convoluted with a Gaussian function of same mean value was also used to fit the signal shape. Fixing the width of the Gaussian to the estimated resolution of 6 MeV/c^2 and letting free the full width of the Breit-Wigner did not change the fitted mass value, but the fitted full width, $4.4^{+6.4}_{-4.4}$ MeV/c^2, was compatible with zero. A 95% C.L. upper limit of 15 MeV/c^2 is derived for the full decay width of the resonance.

The observed signal is likely to come from a $D^{*'}$ radial excitation (2^3S_1) with an expected mass of about $2630 - 2640$ MeV/c^2 [4,8] and a full width which could be of a few MeV/c^2 [6].

Due to the momentum selections applied to the $\pi^+\pi^-$ candidates, the number of entries in the $M(D^{*+}\pi^+\pi^-)$ distribution at low mass values is slightly depleted. In the background parameterization, changing the value of the μ parameter between 280 MeV/c^2 and 360 MeV/c^2 varied the number of fitted events by ± 1, without affecting the fitted mass and width. Changing the selection cuts did not vary the fitted mass by more than its statistical error. The effect of the 4 MeV/c^2 discrepancy in the measured D^0 mass was

found to be less than one MeV/c^2 on the $D^{*'}$ mass because the latter was computed as a mass difference where the measured D^0 mass cancels. A systematic uncertainty of ± 6 MeV/c^2 on the $D^{*'}$ mass can be conservatively inferred from the statistical precision on the D_1^0 and D_2^{*0} fitted masses in section 5.

No signal was found for the decay $D_2^{*+}(2459) \to D^{*+}\pi^+\pi^-$ which is kinematically disfavoured [3] and which was also reduced by the selection cuts.

As a cross-check of the assignment of a radial excitation to the observed signal, the $(\pi^+\pi^-)$ invariant mass distribution was compared to the universal form of ref. [14], assuming the $D^{*'}$ to decay directly into $D^*\pi\pi$. However the available statistics did not allow this prediction to be distinguished from the simple phase space contribution.

Finally, the production fraction of $D^{*'}$ was compared to D_1^0 and D_2^{*0}. According to the simulation, $D^{*'}$ candidates had an overall reconstruction and selection efficiency of about 4% (2%) in the Kπ (K3π) decay mode of the D^0, respectively. The corresponding efficiencies were about 14% (6%) for the observed orbital resonances. From these values and the fitted numbers of D excited states, the relative yield of $D^{*'}$ was inferred:

$$\frac{< N_{D^{*\prime +}} > Br(D^{*\prime +} \to D^{*+}\pi^+\pi^-)}{\sum_{J=1,2} < N_{D_J^{(*)0}} > Br(D_J^{(*)0} \to D^{*+}\pi^-)} = 0.49 \pm 0.18(\text{stat.}) \pm 0.10(\text{syst.}). \qquad (1)$$

As most of the selection criteria of the orbital and radial transitions are similar, their uncertainties cancel in the ratio. The remaining systematics include the statistical error on the simulated samples, the error on the full width of the orbital resonances [1] and the estimate of the kaon rejection efficiency which is applied in the $D^{*+}\pi^+\pi^-$ final state. The uncertainty due to the momentum selection of the final state pions, which may depend on the different decay channels of the $D^{*'}$ (see figure 1), is not taken into account.

The result (1) can be compared with models of primary hadron production. In the thermodynamical approach of ref. [15], particles are assumed to be produced in a hadron gas at thermal and chemical equilibrium with a temperature $T = 160.3 \pm 3.7$ MeV/c^2. In the semi-empirical approach of ref. [16], quark pair creation in a colour string field is assumed to follow a tunnelling process with an effective temperature $T' = 298 \pm 15$ MeV/c^2. In these models, the prediction for the multiplicity of non-strange charm mesons in $c\bar{c}$ events depends only on their mass and total spin:

$$< N_D > \quad \propto \quad (2J+1)\, K_2(m_D/T)\ [15] \qquad (2)$$

$$< N_D > \quad \propto \quad (2J+1)\, e^{-m_D/T'}\ [16], \qquad (3)$$

where K_2 is the McDonald function of order 2 and formula (2) can be approximated as $(2J+1)\, m_D^{1.5}\, e^{-m_D/T}$ in the limit where $m_D \gg T$. The relative proportions of primary charm mesons D_1:D_2^*:$D^{*'}$ will be thus 1:1.35:0.29 [15] and 1:1.47:0.49 [16], respectively. The D_2^* can decay both into Dπ and $D^*\pi$ with the measured partial width ratio , $(D_2^{*0} \to D^+\pi^-)/$, $(D_2^{*0} \to D^{*+}\pi^-) = 2.3 \pm 0.6$ [1] whereas spin-parity conservation prevents the D_1 to decay into Dπ. From isospin conservation, neglecting decays into $D^{(*)}\pi\pi$ or $D^{(*)}\rho$, the following branching fraction can be estimated: $Br(D_1^0 \to D^{*+}\pi^-) = 2/3$ and $Br(D_2^{*0} \to D^{*+}\pi^-) = 0.20 \pm 0.04$. If the $D^{*'}$ decays mainly into $D^*\pi\pi$, neglecting decays into $D_1^{(\prime)}\pi$ or $D_2^*\pi$, isospin conservation infers $Br(D^{*\prime +} \to D^{*+}\pi^+\pi^-) = 1/2$. The relative yield given in eq. (1) is thus predicted to be 0.16 ± 0.01 [15] or 0.25 ± 0.02 [16] for $c\bar{c}$ events. The measured value in Z decays, where both $c\bar{c}$ and $b\bar{b}$ events contribute, is larger than these expectations but has a large uncertainty.

7 Conclusion

Using about 7000 exclusively reconstructed $D^{*\pm}$ mesons, a search for $D^{*+}\pi^+\pi^-$ decay vertices has been performed. A narrow peak is observed in the invariant mass distribution, whose width is compatible with the detector resolution. A signal of 66 ± 14(stat.) events is obtained with an observed mass of 2637 ± 2(stat.) ± 6(syst.) MeV/c^2 and a 95% C.L. upper limit on the full decay width of 15 MeV/c^2. The relative yield of these candidates corresponds to 0.49 ± 0.21 of the production fraction of orbitally excited $D_J^{(*)0}$ decaying into $D^{*+}\pi^-$. This signal is interpreted as the first evidence for a radially excited $D^{*'}$ ($J^P = 1^-$) meson, as predicted in refs. [4,8].

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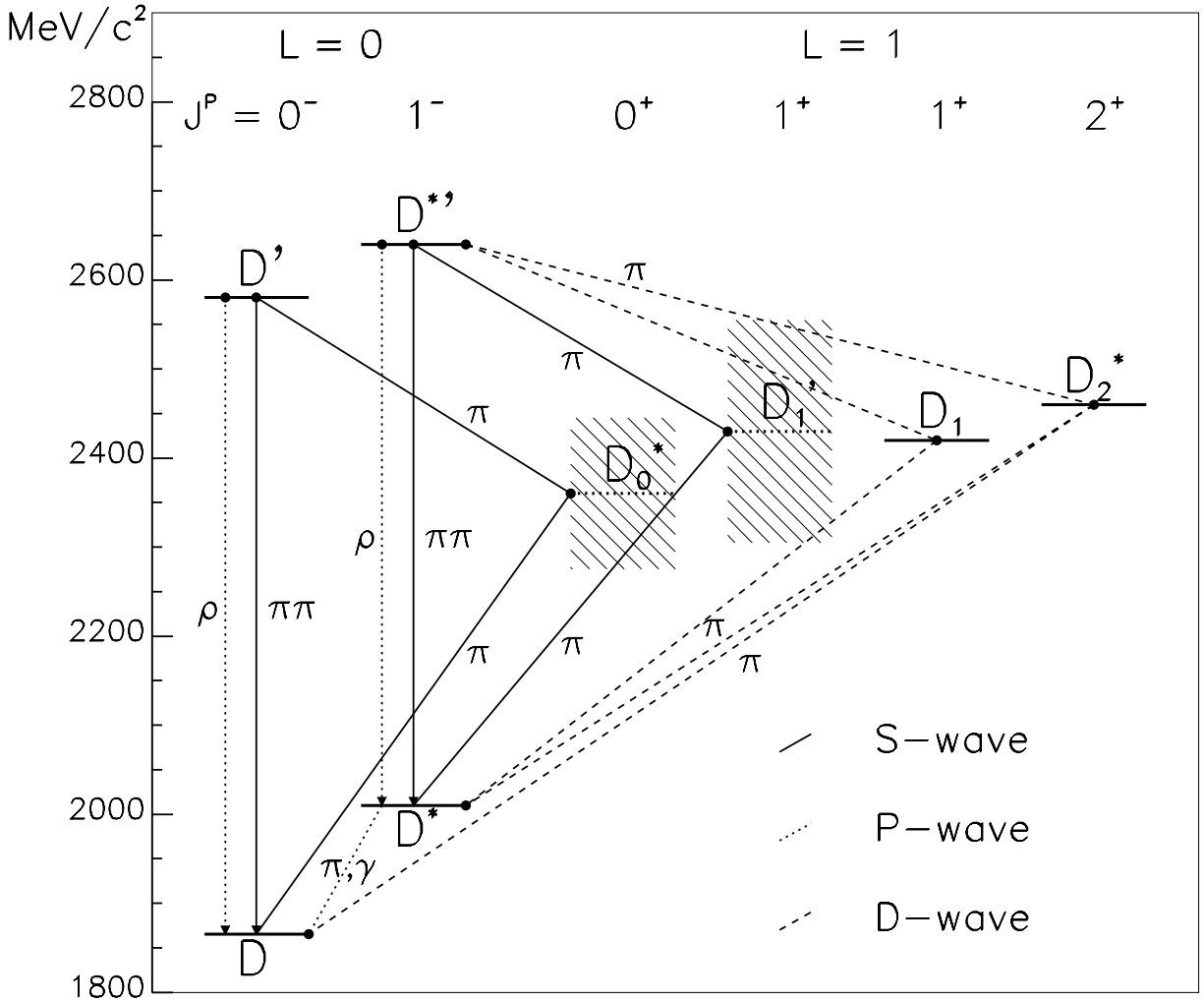

Figure 1: Spectroscopy of non-strange D mesons. The shaded areas show predicted widths for these states. For clarity the expected D_1 and D_2^* decays involving a ρ meson or $\pi\pi$ pair are not shown (see also table 1).

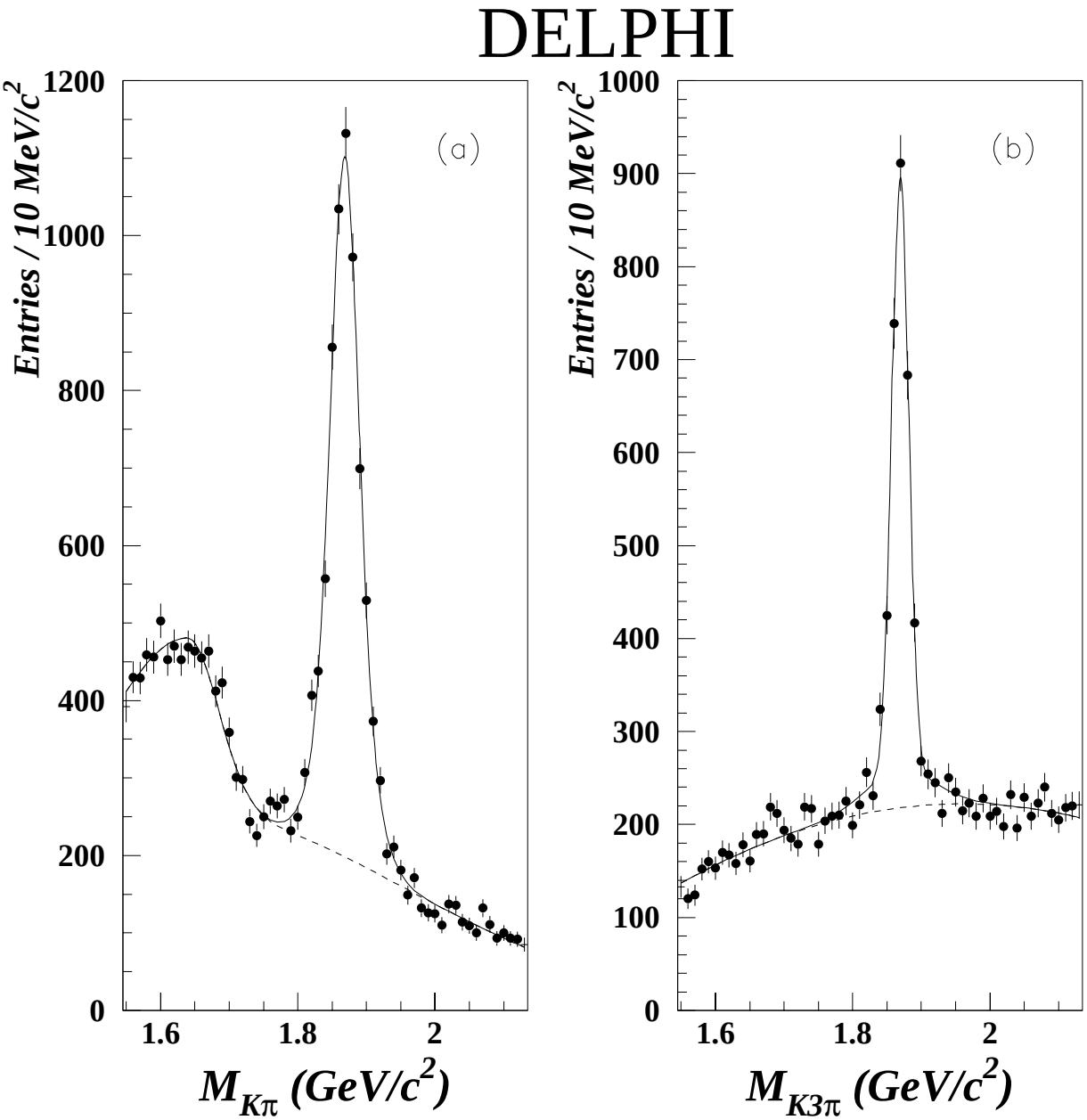

Figure 2: Kπ and K3π invariant mass distributions in (a) the $D^{*+} \to (K^-\pi^+)\pi^+_*$ and (b) the $D^{*+} \to (K^-\pi^+\pi^+\pi^-)\pi^+_*$ decay channels. The full curve is a fit which includes a background parameterization (dashed curve alone) and two Gaussian functions (see section 4).

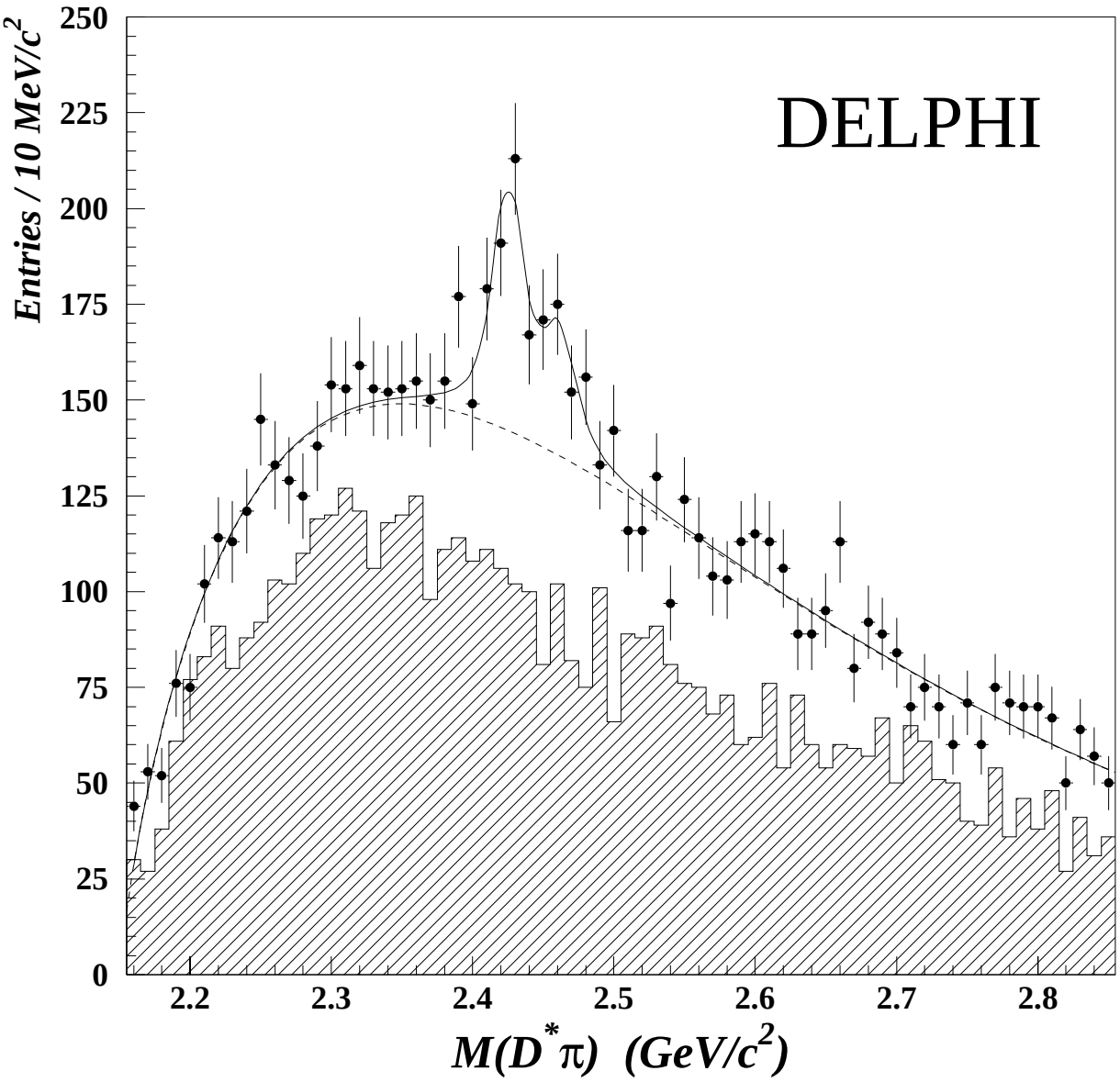

Figure 3: Invariant mass distributions ($D^{*+}\pi^-$) (dots) and ($D^{*+}\pi^+$) (hatched histogram). The mass computation is explained in the text. The full curve is a fit which includes a background parameterization (dashed curve alone) and two Breit-Wigner functions (see section 5).

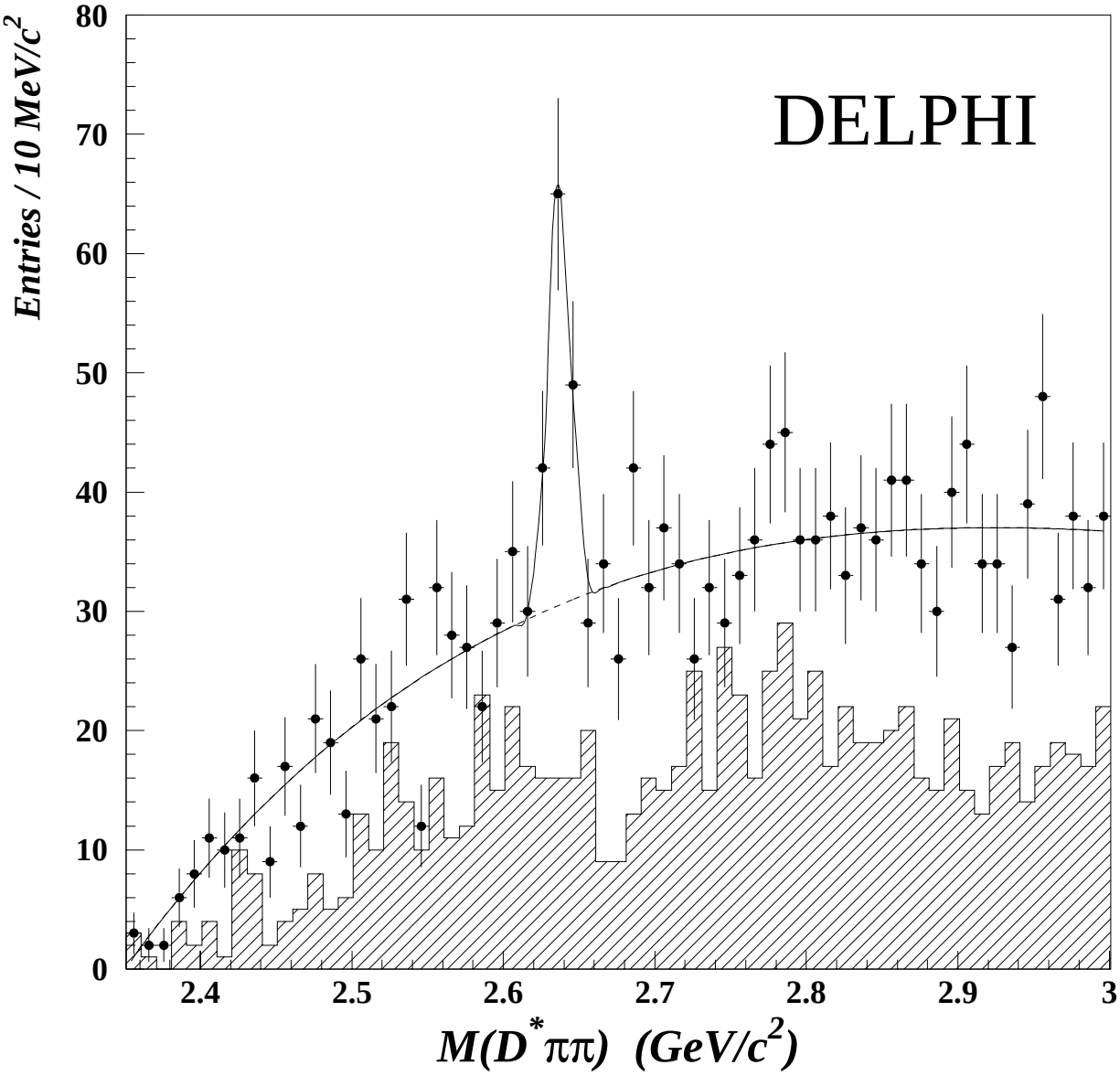

Figure 4: Invariant mass distributions ($D^{*+}\pi^+\pi^-$) (dots) and ($D^{*+}\pi^-\pi^-$) (hatched histogram). The mass computation is explained in the text. The full curve is a fit which includes a background parameterization (dashed curve alone) and a Gaussian function (see section 6).